

# CIRCUIT MODEL FOR PARAMETER STUDY OF MARX GENERATORS ON MEGAJOULE MACHINES\*

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## Abstract

Sandia National Laboratories (SNL) is planning to redesign the pulsed power driver on Z, including the Marx generators, the intermediate-store water capacitors, the laser triggered switches and the pulse-forming lines to increase the energy delivered to a Z-pinch load. The present Marx system consists of 36 generators that store over 11 MJ of energy. Each generator contains sixty 1.30  $\mu\text{F}$  capacitors that are charged in bipolar fashion to 95 kV. The system erects to 5.7 MV when switched, and stores 366 kJ of energy. The 60-capacitors are configured as 12-capacitors to a row and 5-rows to a generator. A circuit model has been developed using MICROCAP [1] to model one of the 36-Marx generators. The model contains the capacitors, inter-stage switches, ground resistors, trigger resistors, and the connection and internal inductance, capacitance, and resistance associated with the generator components. The paper describes the approach used to develop the model, presents the model, validates the model by comparing output to measured data, and shows how parasitic coupling can affect generator performance.

## I. INTRODUCTION

The Marx generators being used on Z were originally designed for use on PBFA II and tested on DEMON [2] [3]. The design of the Marx trigger system on Z has been optimized over time using results from experiments on PBFA I, DEMON, and PBFA II [3] [4].

The new Marx will be required to store twice the energy that is stored in the present Marx. A computer model was developed using MICROCAP that simulates the performance of the existing Marx during erection and discharge. The model includes all of the components shown on the electrical schematic of the Z

Marx plus the connection and internal resistance, inductance, and capacitance associated with the physical components and equipment layout. The model is being used to evaluate the effects of the parasitic coupling on the performance of the Marx and will be used to evaluate generator design changes in the future.

## II. MODEL DEVELOPMENT

The Marx generators on Z are modeled as a simple R-L-C circuit in the SCREAMER model of the Z accelerator. SCREAMER is a transmission line code developed by Sandia to model pulsed power systems. The SCREAMER models of one Marx generator and one intermediate store capacitor were duplicated in MICROCAP, as shown in Figure 1.

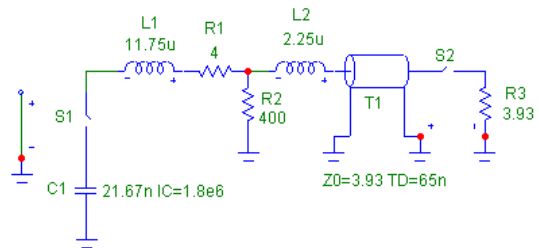


Figure 1. Simple R-L-C model of one Marx generator and one intermediate store

Capacitor C1 represents the sixty 1.30  $\mu\text{F}$  capacitors that are connected in series when the Marx system erects. The initial voltage condition on capacitor C1 is the erected voltage of the Marx. The values of the inductor and resistor in the SCREAMER model were determined by comparing the current output from the model to the current measured during ring over tests on

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Z. The sixty 1.30  $\mu\text{F}$  capacitors were charged to 30 kV during the ring over test. The capacitor in the Marx model was set at 21.67 nF and charged to 1.8 MV and the intermediate store output switch opened. The inductor and resistor in the model were varied with each run until the ringing frequency and damping of the model current waveform matched that of the measured current waveform. The SCREAMER model was duplicated in MICROCAP. The simple Marx model was expanded to include all 60 capacitors, 30 switches, and the resistors associated with the Marx erection and discharge events.

Resistance was added to the model as switch resistance, 0.133 Ohms per switch. Internal inductance was added to the model as a 0.2  $\mu\text{H}$  inductor connected between each capacitor and the switch in each stage.

The switch in each Marx stage was modeled as a simple voltage controlled closing switch. All switches were externally triggered using a 80 ns rise, 500 kV ramp waveform. In reality, only the switches in the first two rows of the Marx on Z are externally triggered. Voltages developed in preceding rows internally trigger the switches in the other three rows. The present switch model does not remain closed after the internal trigger voltage falls below the initial trigger threshold. A new switch model is needed. The new switch must close when the voltage threshold is exceeded and remain closed until the Marx is fully discharged.

Parasitic capacitors were added to the model, between capacitor cases in a column and between capacitor cases in adjacent rows. The configuration of the Marx capacitors in one module on Z is shown in Figure 2.

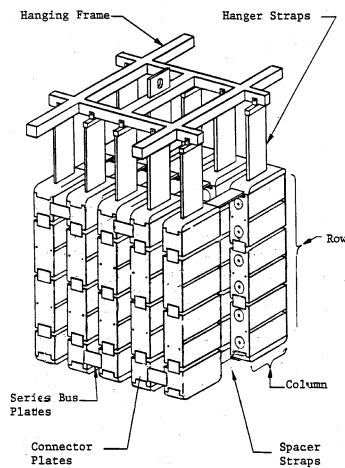


Figure 2. Configuration of capacitors in one Marx module on Z

Each Marx capacitor is 14" high, 11" deep, and 25" wide. The parasitic capacitors were modeled as parallel plate capacitors with an oil dielectric between the plates. The permittivity of oil is 2.3. The capacitance of the column parasitic capacitors was calculated as 71 pF and the row-to-row parasitic capacitance is 23 pF. The capacitance was calculated using the expression:

$$C = 0.225 \cdot \epsilon_r \cdot A/d$$

Where C is capacitance in pF  
 $\epsilon_r$  is relative permittivity of oil  
 A is plate area in sq in  
 d is plate spacing in in

### III. MODEL VALIDATION

The current output from the simple model is compared to the current measured on calibration shot No. 5316 on Z in Figure 3.

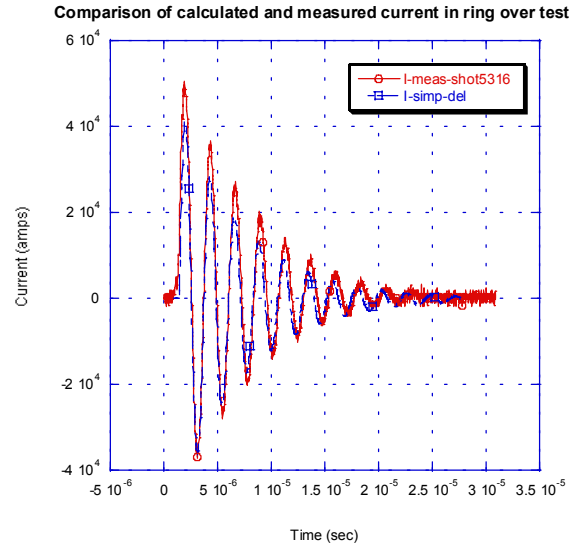


Figure 3. Comparison of current output from simple model with current measured during ring over test

The current output from the model with no inductance and that from the model expanded to include series resistance and inductance are compared to the current output from the simple model in Figure 4. It is apparent from the comparison that the Marx model must include series inductance. When the inductance and resistance are included in the model, the output compares very well with the simple model, and hence the measured data.

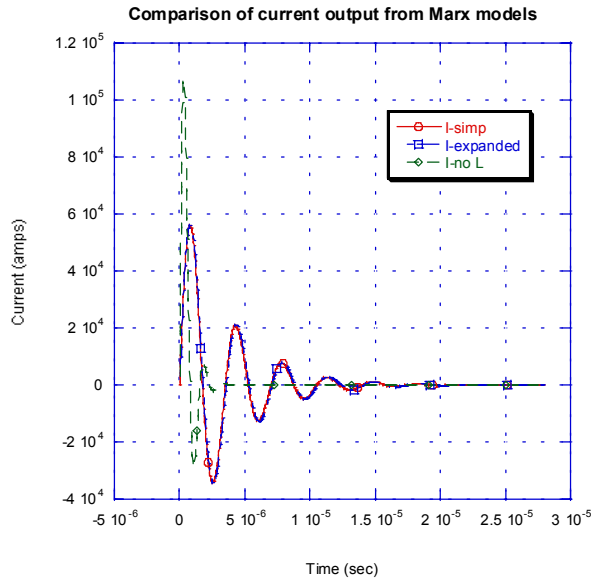


Figure 4. Comparison of current output from different models

## IV. MARX PERFORMANCE RESULTS

Adding parasitic capacitance, both column and row affects the performance of the Marx, especially in the early time. This is apparent in Figure 5. It was found that the row-to-row capacitance has a greater affect on the output voltage than does the column capacitance. Neither has much of an affect on the current output.

The model of the Z Marx that incorporates the internal inductance and resistance of the Marx components and the row-to-row and column parasitic capacitance is presented in Figure 6.

## V. CONCLUSIONS

The Marx generator on Z can be modeled accurately using the commercial circuit analysis program, MICROCAP, provided the model includes the series inductance and resistance, associated with the inter-stage capacitors and switches.

The parasitic capacitance may not affect the Marx performance because the transient disturbance appears to occur only during the time frame of the external trigger. If the disturbance is prolonged so as to affect the internal trigger sequence, it could increase switch jitter and degrade Marx performance. This can be investigated after a new time-dependent switch model is developed and incorporated into the Marx model.

The new switch model must be developed for use in modeling the internal trigger sequence. The switch must

close when triggered and remain closed until the Marx is fully discharged. It is also desirable to include a time-varying resistance to more accurately model the evolution of the spark channels in the switches.

The model validation is not complete. Additional comparisons of model and measured voltages at 30 kV charge are still needed. The comparisons of model and measured results are needed at other charge levels as well.

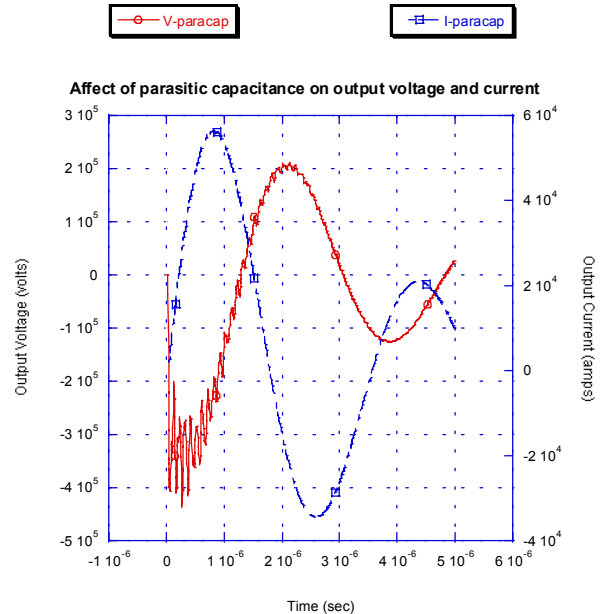


Figure 5. Voltage and current output from Marx model with parasitic capacitance

## VI. REFERENCES

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